Ground Motion Selection for Seismic Response Analysis

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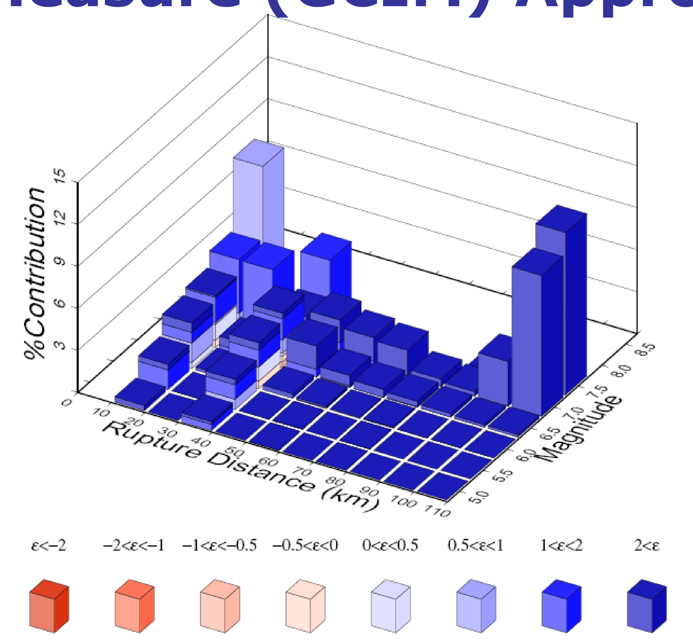
1. Background and Objective

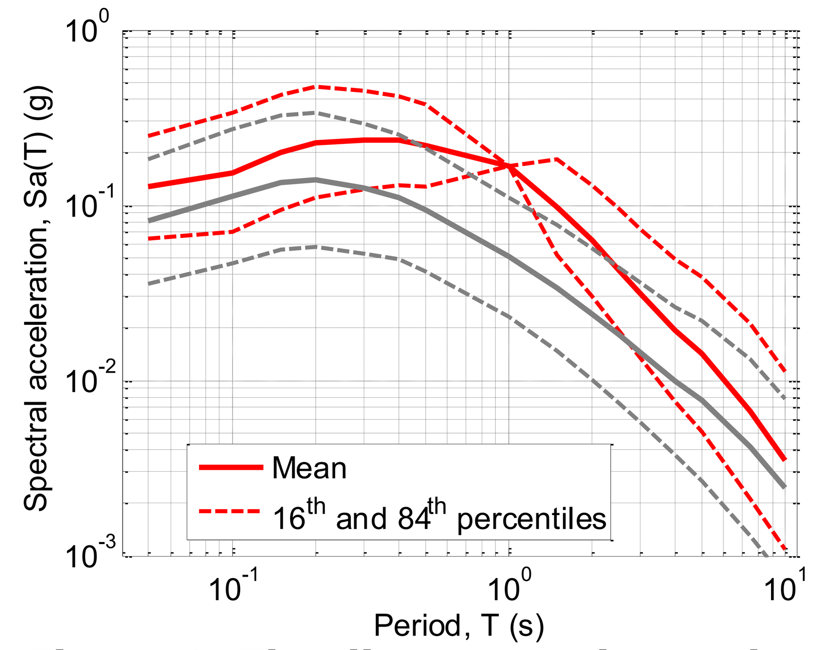
The rigorous selection of ground motions is an important consideration in a seismic risk assessment as it provides the link between seismic hazard (seismology) and seismic response (earthquake engineering). Despite the fact that many studies have highlighted the differences between the uniform hazard spectrum (UHS) and individual earthquake scenarios, the UHS is still the primary method by which ground motion records are selected and scaled. The conditional mean spectrum (CMS) is one alternative to the UHS for ground motion selection which provides the mean response spectral ordinates conditioned on the occurrence of a specific value of a single spectral period, and is directly linked to probabilistic seismic hazard analysis (PSHA). There are however several limitations in the use of the CMS for ground motion selection, which primarily stem from the fact that spectral accelerations provide only a partial picture of the true character of a ground motion.

Based on the identified limitations of the CMS the objective of this work was to develop what is referred to as a generalised conditional intensity measure (GCIM) approach, which allows for the construction of the conditional distribution of any ground motion intensity measure. A holistic method of ground motion selection was also developed based on the comparison of the empirical distribution of a ground motion suite and the GCIM distributions.

2. The Generalised Conditional Intensity Measure (GCIM) Approach

The fundamental basis of the GCIM approach is that for a given earthquake scenario (*Rup*) the joint distribution of a vector of intensity measures (i.e. $\boldsymbol{IM}|Rup$) has a multivariate lognormal distribution. The validity of this assumption and mathematical details are elaborated upon in Bradley (2010). Characterisation of $\boldsymbol{IM}|Rup$, therefore requires the marginal distributions, $IM_i|Rup$ and correlations between IM_i and IM_j for which several prediction equations already exist. The total probability theorem can then be used to construct the conditional distribution of any intensity measure given the occurrence of a specific value of another intensity measure. The figure below illustrates the seismic hazard disaggregation for Christchurch, New Zealand, for one-second spectral acceleration, Sa(1.0), which has an annual exceedance probability of 1/475; as well as the conditional spectral acceleration and Arias Intensity distributions given Sa(1.0).





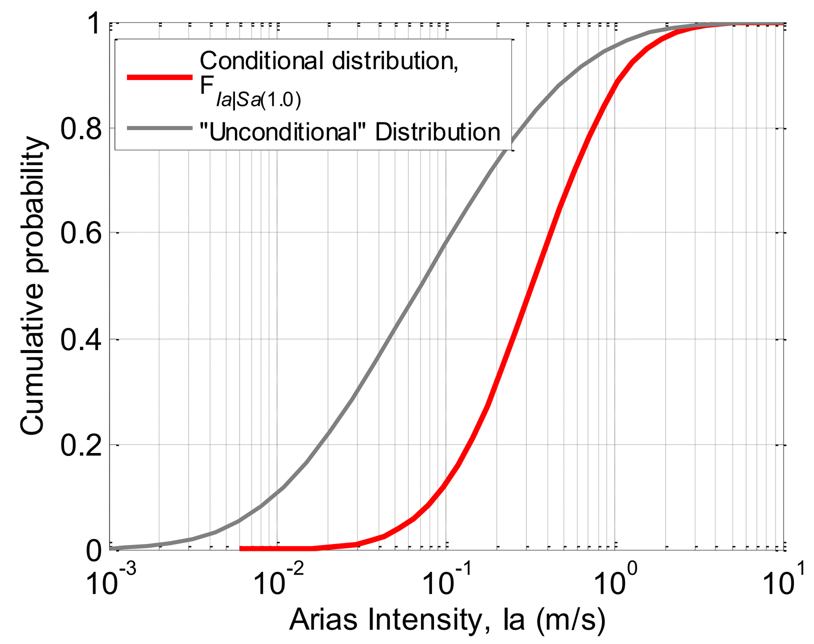


Figure 1: The disaggregation and example conditional distributions for a site in Christchurch, New Zealand.

3. Holistic Ground Motion Selection

The GCIM approach provides the exact distribution (for the given inputs in a PSHA) of intensity measures of potential ground motions with $IM_j = im_j$ which may be observed at the site. The GCIM distributions are therefore the 'target' which should be used in selecting a suite of ground motions.

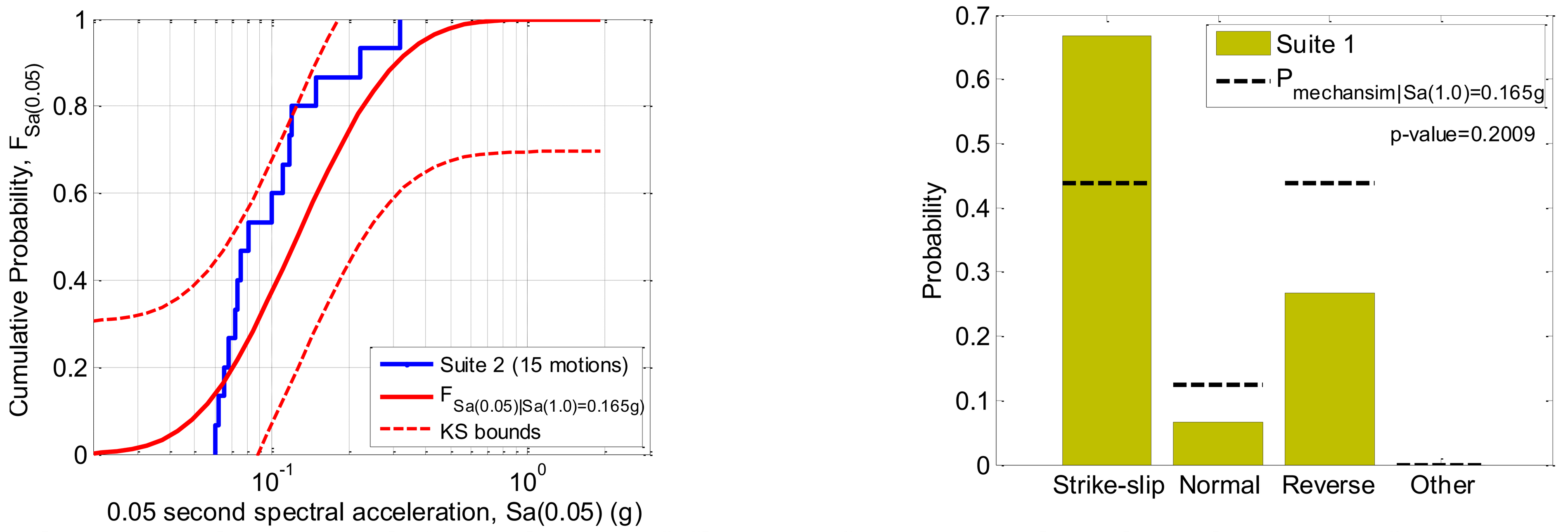


Figure 2: The KS and χ^2 goodness-of-fit tests for comparing the adequacy of a ground motion suite for continuous and discrete intensity measures.

Because only a finite number of ground motions are desired for seismic response analysis, then determination of the representativeness of the ground motion suite with respect to a certain intensity measure must be quantified using statistical tests. Two such tests for continuous and discrete intensity measures are shown in Figure 2.

Figure 3 illustrates two suites of ground motions that were selected for the example Christchurch site previously mentioned (suite 1 M<6,R<20km; Suite 2 M>7,R>50km). Figure 3a illustrates the response spectra of the unscaled motions, while Figure 3b illustrates the spectra when the ground motions are conditioned on Sa(1.0). Figures 3c and 3d illustrate the comparisons of the conditional distributions of Arias Intensity and Significant Duration of the two suites with the theoretical GCIM distributions.

It can be seen that a significant amount of additional information about the representativeness of a ground motion suite with respect to various intensity measures can be obtained. Such information is clearly of benefit when investigating the appropriateness of modified and stochastically simulated ground motions, as well as amplitude scaling of as-recorded ground motions.

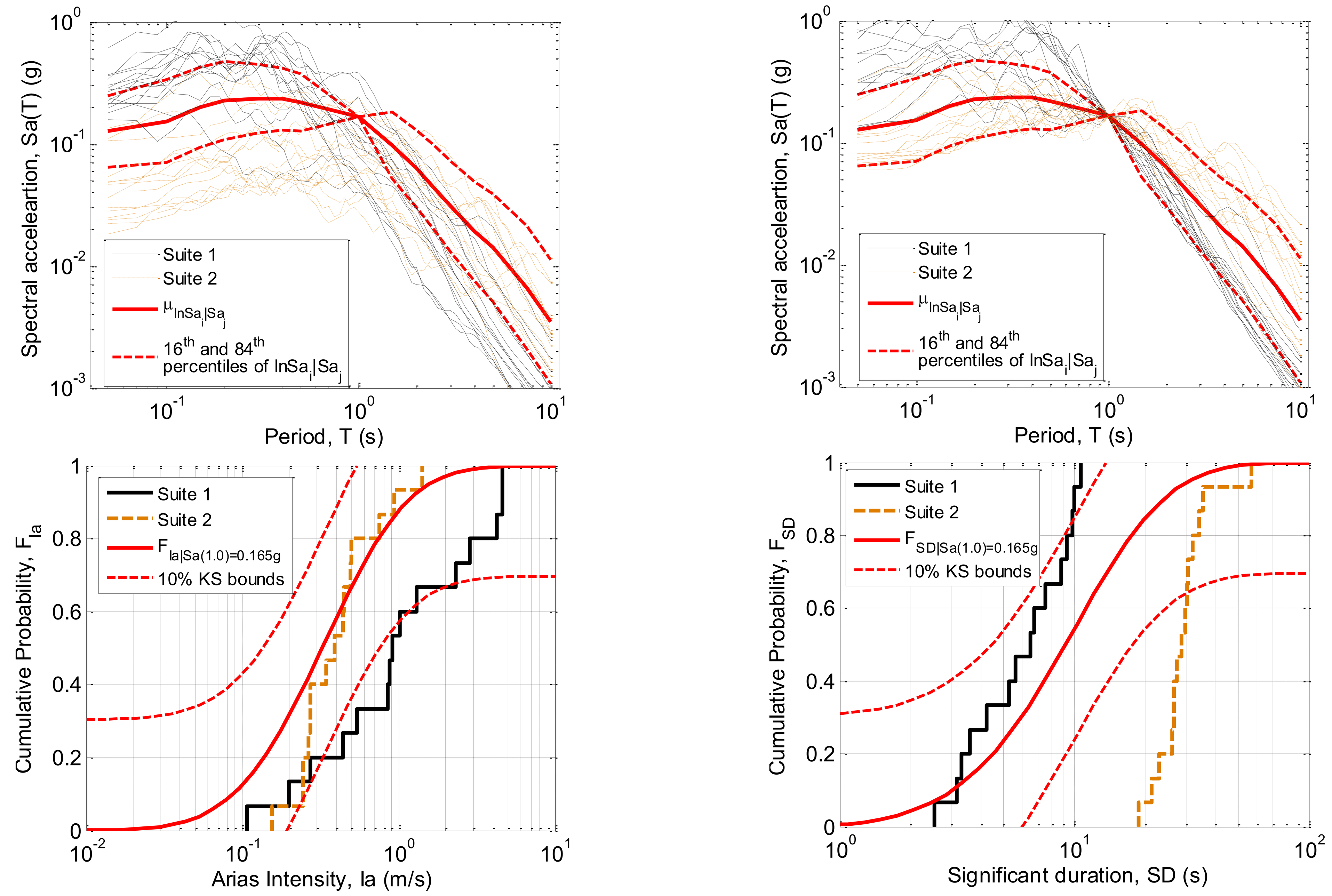


Figure 3: Comparison of two ground motion suites with the GCIM distributions.

4. Bias in Seismic Response from Incompatible Ground Motions

If a ground motion suite is selected which is not consistent with the GCIM distribution for a particular intensity measure, then there is possibly bias in the seismic response analysis if it is dependent on this intensity measure. The bias can be simply estimated using the dependence of the seismic response distribution and determine whether a new suite of (more representative) ground motions should be selected.

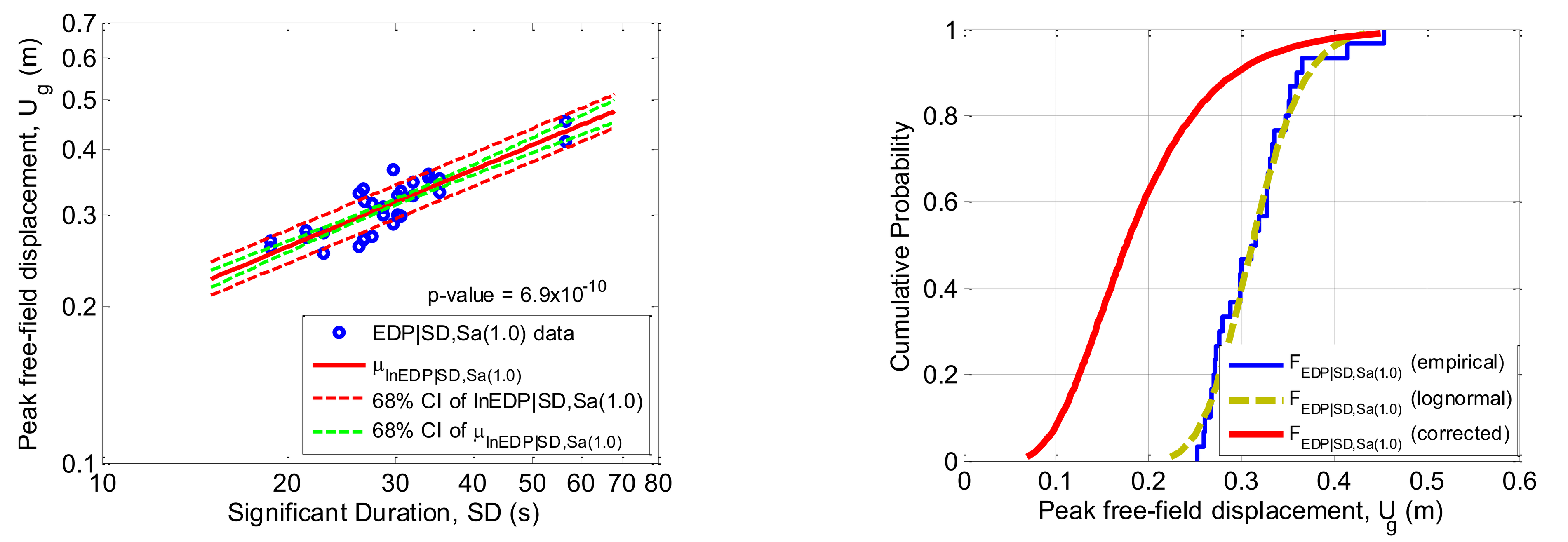


Figure 4: Bias estimation of the seismic response analysis results.

5. References

Bradley, B.A. (2010) A Generalised Conditional Intensity Measure Approach and Holistic Ground Motion Selection. ***Earthquake Engineering and Structural Dynamics*** (in press – available online or from the author via email)